POSITIVE STREAMER PROPAGATION AND BREAKDOWN CHARACTERISTICS IN NON-UNIFORM AIR GAP

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Abstract: Discharge phenomena in a needle-plane electrode in air were studied with nano-second time resolution by means of synchronous measurement. A secondary streamer initiated after the primary streamer arrived at the plane electrode. There are close relations between the applied voltage, the primary and the secondary streamer current and the initiation time of the secondary streamer. The breakdown can start when the secondary streamer arrived at the plane electrode. The time-to-breakdown becomes shorter with the increase of the secondary streamer current.

1. INTRODUCTION

High-voltage power apparatuses become more compact and larger capacity. To achieve their high reliability, a clarification of discharge initiation and propagation characteristics is required.
In this paper, we have measured waveform and image of discharge using ultra high-speed synchronous discharge measurement system. We studied streamer propagation characteristic and relation between streamer propagation and BD.

2. RESULTS AND DISCUSSION

Figure 1 shows the relation between primary streamer current and Δt_{2nd} in a needle-plane electrode (g = 15, 30, 40 mm). Δt_{2nd} is the time interval between the primary and secondary streamer. Δt_{2nd} decreases as primary streamer current increases and gap length becomes shorter. Secondary streamer initiates by electrons injected from the plane electrode when primary streamer arrives at the plane electrode [1]. Injected electrons from the plane electrode increase as a function of primary streamer current, and arrival time is shorter in a short gap. Therefore, secondary streamer initiates more easily.

Figure 2 shows an example of applied voltage, discharge current and fast-framing images of discharge leading to BD (V_a = 30 kV, g = 15 mm). Though electrical conducting path bridging the gap is formed when secondary streamer have reached the plane electrode, BD does not occur because conductivity of the channel is not high enough. When the electrons injected from the plane electrode move in the channel, the electrons obtain energy from electric field and give the energy to the channel, and temperature of the channel rises. BD occurs if the conductivity of the channel becomes enough high.

3. CONCLUSION

We clarified that there is a close relation between primary and secondary streamer, and electrical conducting path is heated by the electrons and the conductivity of the channel rises. BD occurs if the conductivity becomes enough high.

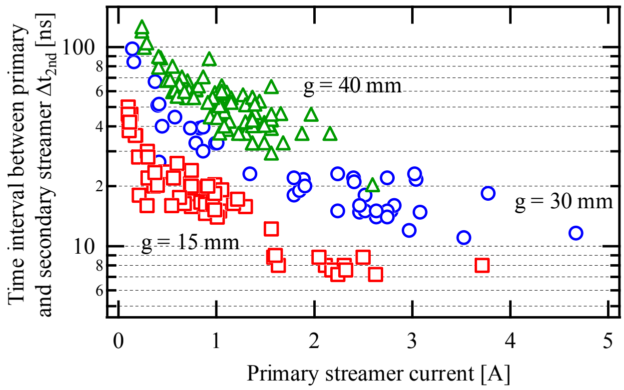
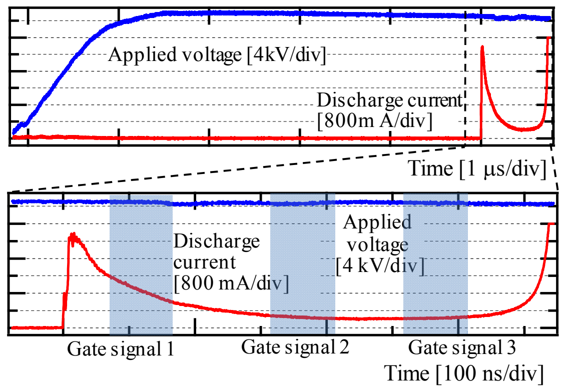
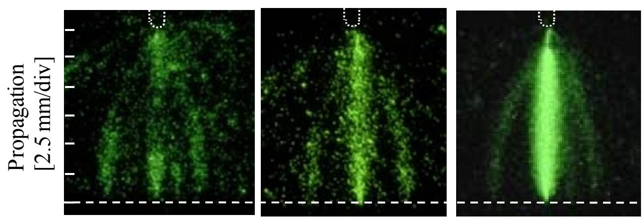


Fig.1 Relation of Δt_{2nd} and primary streamer current



(a) Discharge current waveform



(b-1) Gate signal 1 (b-2) Gate signal 2 (b-3) Gate signal 3

(b) Fast-framing image of discharge

Fig.2 Discharge current waveform and image of BD

4. REFERENCES

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Positive Streamer Propagation and Breakdown Characteristics in Non-uniform Air Gap

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***Abstract*— Discharge phenomena in a needle-plane electrode in air were studied with nano-second time resolution by means of synchronous measurement of streak image, light intensity, discharge current and fast-framing image. When positive impulse voltage was applied, a primary streamer initiated from the needle tip and propagated to the grounded plane electrode. A secondary streamer initiated after the primary streamer arrived at the plane electrode. There are close relations between the applied voltage, the primary and the secondary streamer current and the initiation time of the secondary streamer. The breakdown can start when the secondary streamer have arrived at the plane electrode. Moreover, the time to breakdown becomes shorter with the increase in the secondary streamer current.**

I. INTRODUCTION

Atmospheric air is used for insulation media of many high-voltage power apparatuses. Nowadays, they become more compact with larger capacity. Then, the operating electric field strength becomes higher. To achieve their high reliability, clarification of discharge initiation and propagation characteristics in non-uniform electric field is required. In air, a secondary streamer initiates after the primary streamer have reached the plane electrode [1, 2]. If the secondary streamer bridges the gap, breakdown occurs after a few microseconds [3,4]. However, since discharge phenomena in non-uniform electric field are complex, the breakdown mechanism is not clear.

From this background, we aim to clarify the mechanism of discharge from initiation to breakdown (BD) in non-uniform air gap and to quantify influential factors. In this paper, we measured current and light intensity waveforms of discharge, fast-framing image and streak image using ultra high-speed synchronous discharge measurement system. We focused on the streamer propagation characteristics and the relation between streamer propagation and BD.

II. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup. We set needle-plane electrode (gap length g = 15, 30, 40 mm) in a tank filled with dry air (0.1 MPa). Electrodes are made by SUS304 stainless steel, and tip diameter and length of needle electrode is 1 mm and 20 mm, respectively. We apply positive lightning impulse voltage (1.2/50 μs) and generate the discharge in the air gap.

We measure the discharge current waveform through a measuring resistor and the light intensity waveform using a photomultiplier tube. We measure fast-framing images of the discharge using a digital camera with an image intensifier (I.I.) [5]. We take three images successively with three cameras whose exposure time is controlled in nanoseconds. At the same time, using a streak camera, we obtain ultra high-speed streak images to measure the transition of discharge which initiates and propagates in nanoseconds.

The streak camera, digital cameras and oscilloscope are synchronized by a pulse generator. We can measure synchronously the discharge current and light intensity waveforms, fast-framing image and streak image.

III. EXPERIMENTAL RESULTS

A) Ultra high-speed and synchronous measurement of discharge

Figure 2 shows the experimental results using the above-mentioned ultra high-speed and synchronous measurement system of discharge when we applied the positive lightning impulse voltage of 28 kV in the air gap (g = 15mm) and measured the propagation of the discharge. Though branching streamers reached a plane electrode as shown in Figure 2(c), BD did not occur. Figure 2(b) shows the streak image of discharge propagation from the needle electrode to the plane electrode. Focusing on the discharge current and light intensity waveforms shown in Figure 2(a), there are two peaks; the

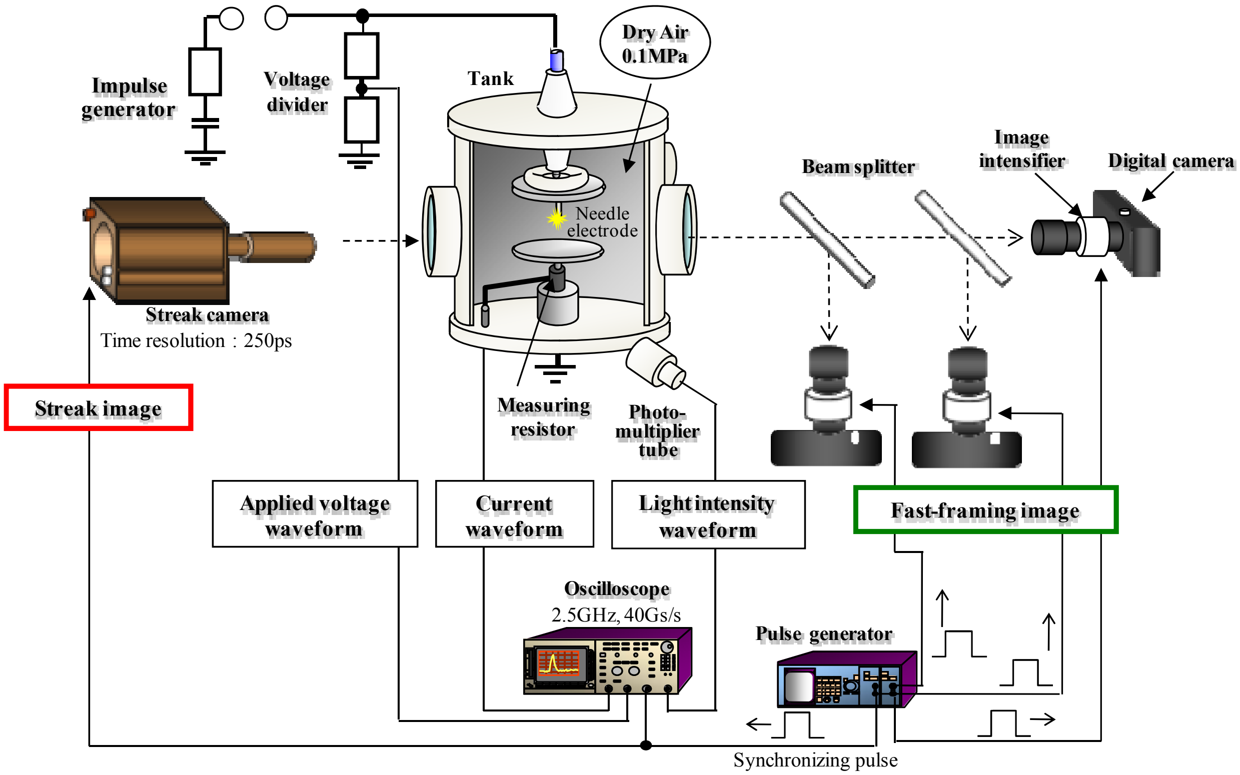


Fig.1 Experimental setup

second peak appeared around 20 ns after the first peak. Together with the luminescence in Figure 2(b) corresponding to the discharge current and light intensity waveforms in Figure 2(a), it is considered that they correspond to the primary and the secondary streamer, respectively [6]. Discharge current reaches a peak when the secondary streamer mostly propagates. However, the light intensity arrives at a peak when the secondary steamer initiates, because the light intensity of the secondary streamer is added to that of the primary streamer.

B) Characteristics of primary and secandary streamer

Figure 3 shows an example of a discharge current waveform. The first peak (a) of discharge current is primary streamer and the second peak (b) is secondary streamer. The time interval between the primary and secondary streamer is defined as Δt_{2nd}. The first peak is defined as primary streamer current, and the peak of discharge current is defined as secondary streamer current. The time from secondary steamer to BD is defined as Δt_{BD}.

Figure 4 shows relation between primary streamer current and instantaneous voltage (g = 15, 30, 40 mm), when the primary streamer initiates. Primary streamer current increases with the increase in instantaneous voltage, and also becomes larger for shorter gap, which is attributed to the activated ionization around the needle tip with the higher electric field strength.

Figure 5 shows the relation between Δt_{2nd} and primary streamer current (g = 15, 30, 40 mm). Δt_{2nd} decreases as primary streamer current increases and gap length becomes shorter. This can be explained from the initiation mechanism of secondary streamer. The mechanism is shown as follows.

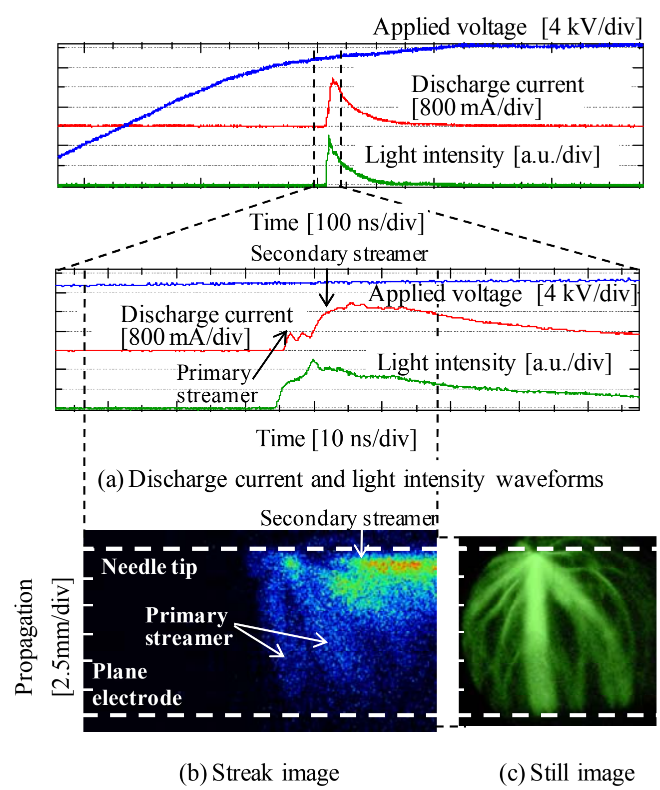


Fig.2 Discharge waveforms and images
(V_a = 28 kV, g = 15 mm)

(i) When primary streamer reaches the plane electrode, the streamer channel is left and the electron is injected into the channel from the plane electrode.

(ii) The resistance of the streamer channel becomes higher near the needle electrode than near the plane electrode according to the electron density distribution along the channel.

(iii) Secondary streamer initiates when the voltage in the gap is redistributed along the streamer channel in proportion to its resistance and the resultant electric field at the needle electrode rises.

Residual charge in the channel and injected electrons from the plane electrode increase as a function of primary streamer current. Therefore, the difference in the channel resistance between near the needle electrode and near the plane electrode is large, and the electric field at the needle electrode is higher. Moreover, arrival time of primary streamer is shorter in a short gap. For these reasons, Δt_{2nd} could decrease because secondary streamer initiates more easily.

From the above mentioned, primary streamer propagation depends on instantaneous voltage and influences the time interval between the primary and secondary streamer.

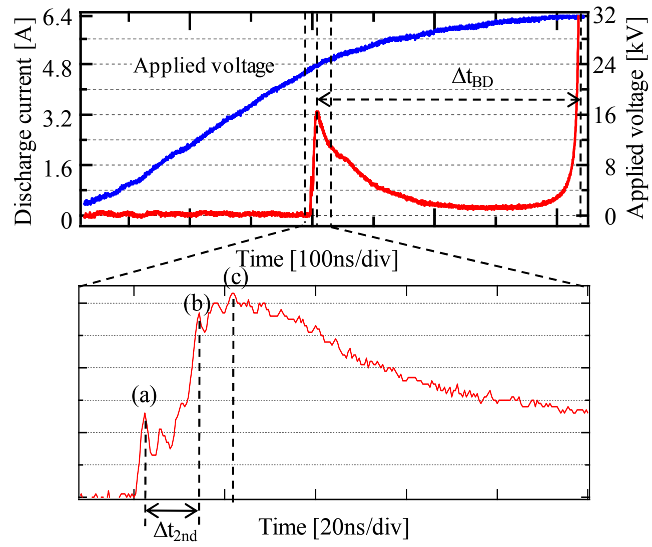
C) Breakdown mechanism

Figure 6 shows an example of applied voltage, discharge current and fast-framing images of discharge leading to BD (V_a = 30 kV, g = 15 mm). After the secondary streamer current reached a peak, it decreased rapidly to almost zero. But after 1.8 μs, discharge current rose again and breakdown occurred. The optical gate signals of three cameras are adjusted to take the framing images of discharge for each 100 ns during its propagation. The image (b-1) is taken by [gate signal 1] during the decrease of secondary streamer current. The image (b-2) is taken by [gate signal 2] when secondary streamer was almost zero. The image (b-3) is taken by [gate signal 3] just before discharge current rose again.

The image (b-1) shows that several secondary streamers propagate and reached the plane electrode. The image (b-2) shows that electrical conducting path bridges the center of gap and its luminosity is stronger than that of the others. The image (b-3) shows that the luminosity of electrical conducting path at the center is further brightened markedly due to the activated ionization.

From these images, it is understood that electrical conducting path whose conductivity is the largest is selected and kept after secondary streamer arrived at the plane electrode. The mechanism of BD is considered as follows. Though electrical conducting path bridging the gap is formed when secondary streamer have reached the plane electrode, BD does not occur because conductivity of the channel is not high enough. When the electrons injected from the plane electrode move into the channel, the electrons obtain energy from the applied electric field and give the energy to the channel, which increase the temperature and the conductivity of the channel. BD occurs if the conductivity of the channel becomes enough high.

Figure 7 shows the relation between Δt_{BD} and secondary streamer current for different oxygen density and humidity in air. Δt_{BD} becomes long in the order of N_2, 2%O_2/98%N_2, dry air, air (humidity 75%) , that is, according to the electronegativity. As shown above, it is considered that BD occurs when electrons give energy to the molecules in the channel and electrical conductivity rises. Electrons can be easily attached to oxygen



(a) Primary streamer current
(b) Initiation of secondary streamer
(c) Secondary streamer current
Δt_{2nd}: Time interval between the primary and secondary streamer
Δt_{BD}: Time from secondary steamer to BD

Fig.3 Definition of primary and secondary streamer current and time to BD

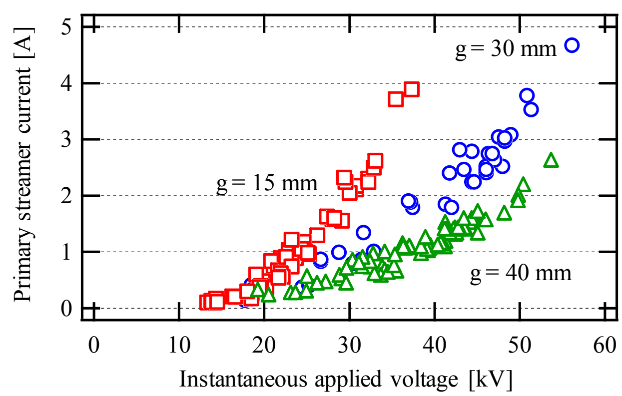


Fig.4 Relation between primary streamer current and instantaneous applied voltage

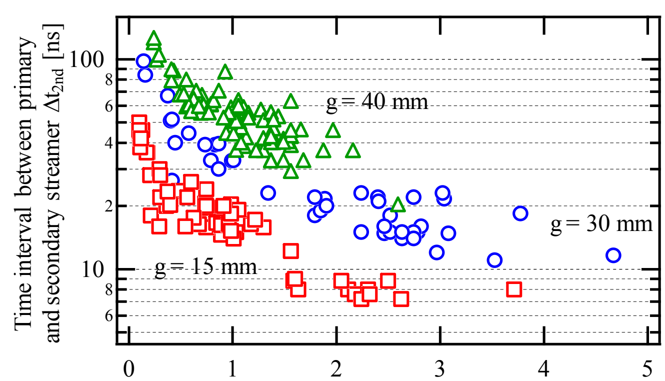


Fig.5 Relation between Δt_{2nd} and primary streamer current

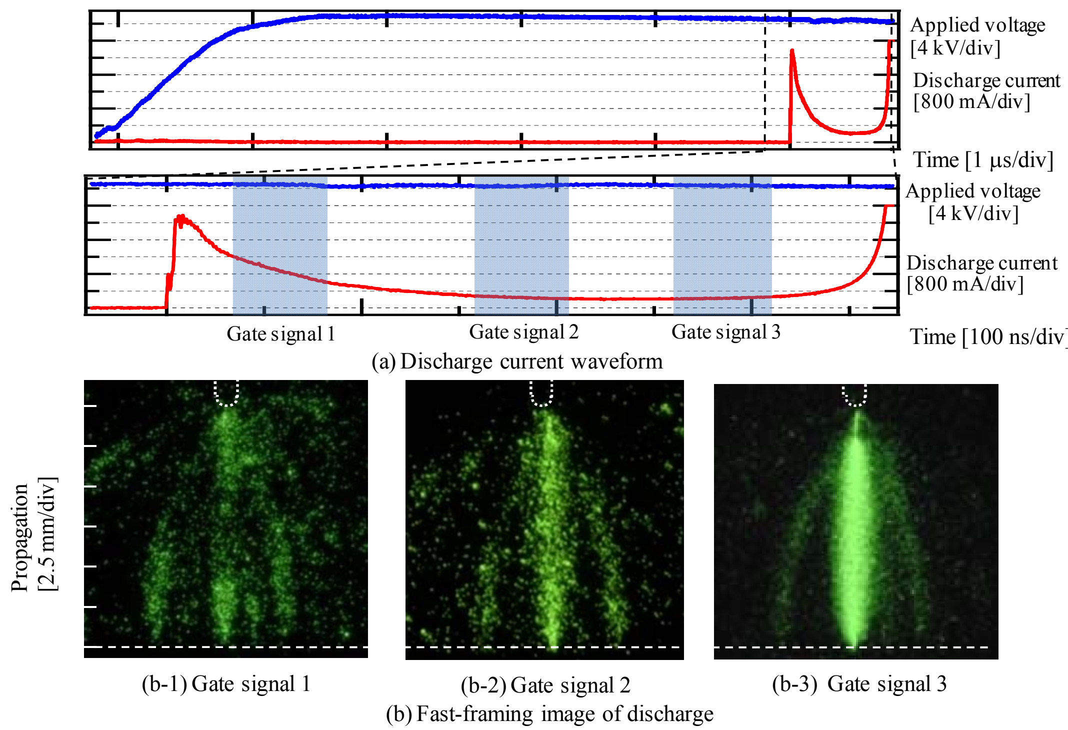


Fig.6 Discharge current waveform and fast-framing images leading to BD (V_a = 30 kV, g = 15 mm)

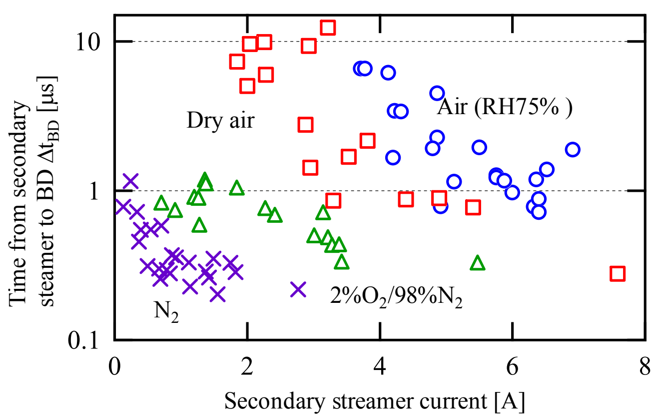


Fig.7 Relation between Δt_{BD} and secondary streamer current

molecules as the oxygen density and humidity increase, and the number of electrons that raise the temperature of the channel decreases. Therefore, it is considered that the longer time or larger secondary streamer current is needed to induce BD for gases with the higher electronegativity

IV. Conclusion

In the breakdown of dry air, current and light intensity waveforms of discharge, fast-framing image and streak image have been measured by using ultra high-speed synchronous discharge measurement system. We studied correlation of primary and secondary streamer with the mechanism of streamer propagation and BD. As a result, we clarified the followings;

(1) Primary streamer current increases with the increase in instantaneous applied voltage, and also becomes larger for shorter gap for a certain voltage because of activated ionization around the needle tip with the higher electric field strength.

(2) Secondary streamer initiates because the electron is injected from the plane electrode after primary streamer reached the plane electrode. Therefore, secondary streamer initiates more easily if primary streamer is larger because residual charge in the channel and injected electrons from the plane electrode increase.

(3) Electrical conducting path whose conductivity is the largest is selected after secondary streamer reached the plane electrode. It is heated by electrons and the conductivity of the channel rises. It is considered that BD occurs if the conductivity becomes enough high.

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